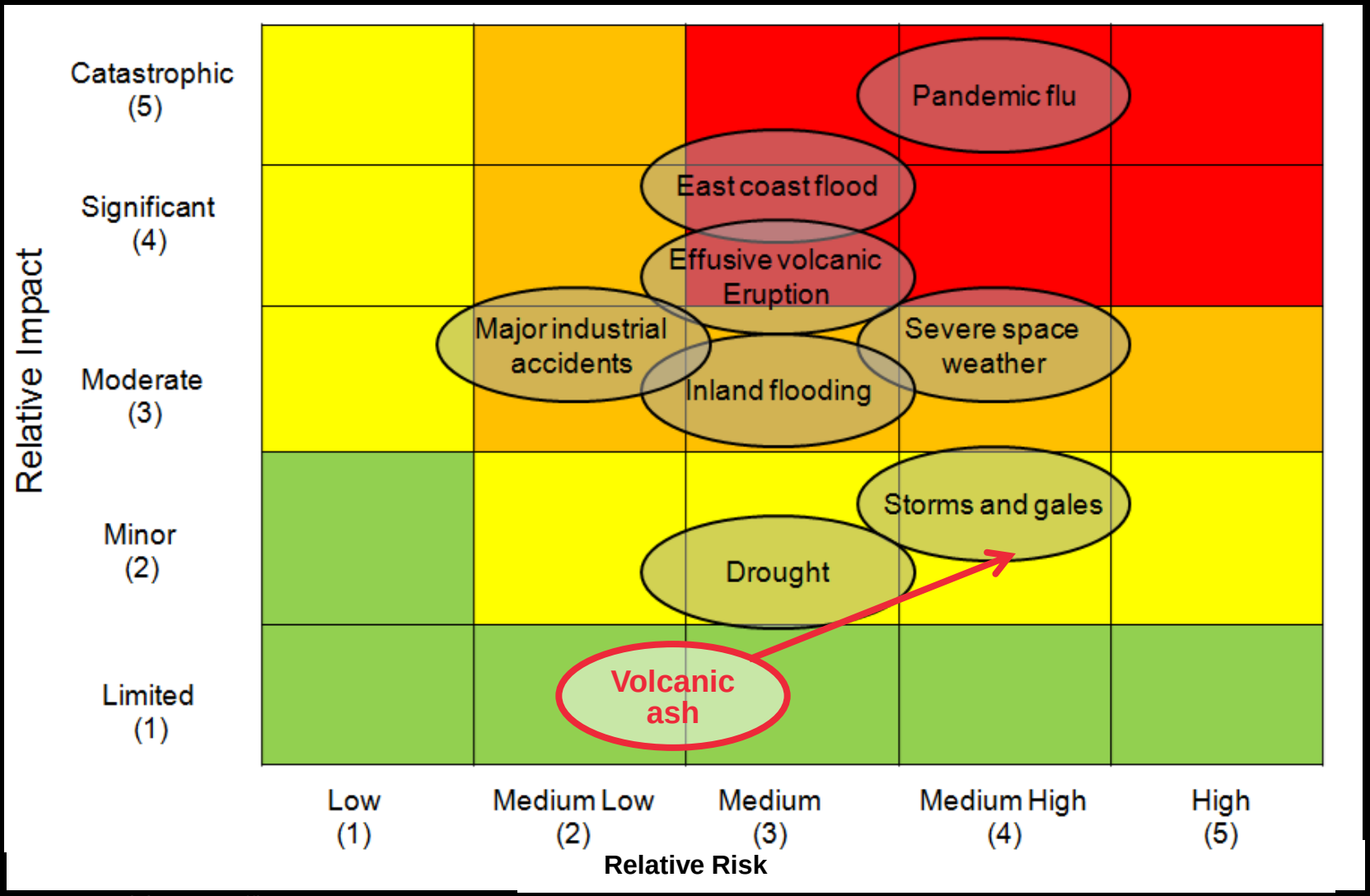
Space Weather - UK Activity

Mark Gibbs, Head of Space Weather

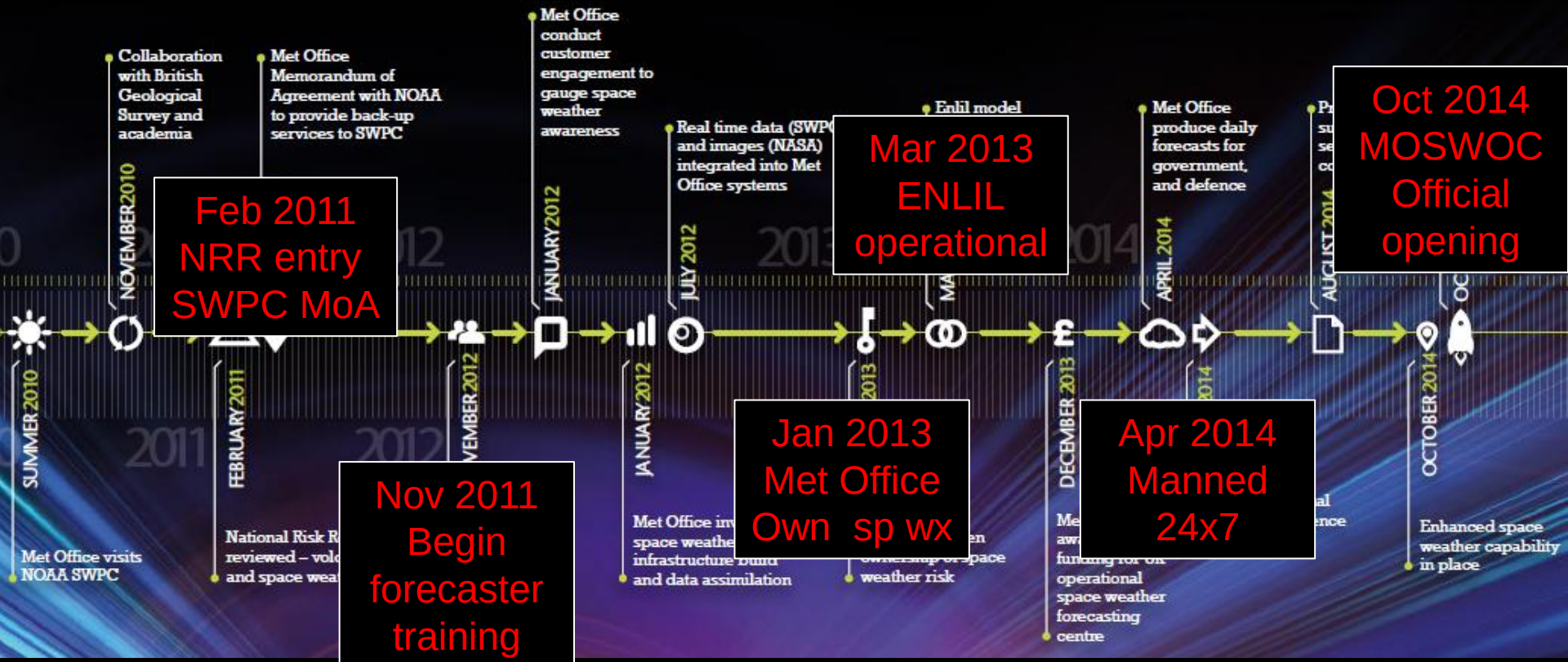
Met Office

Background



Met Office

A space weather journey through time



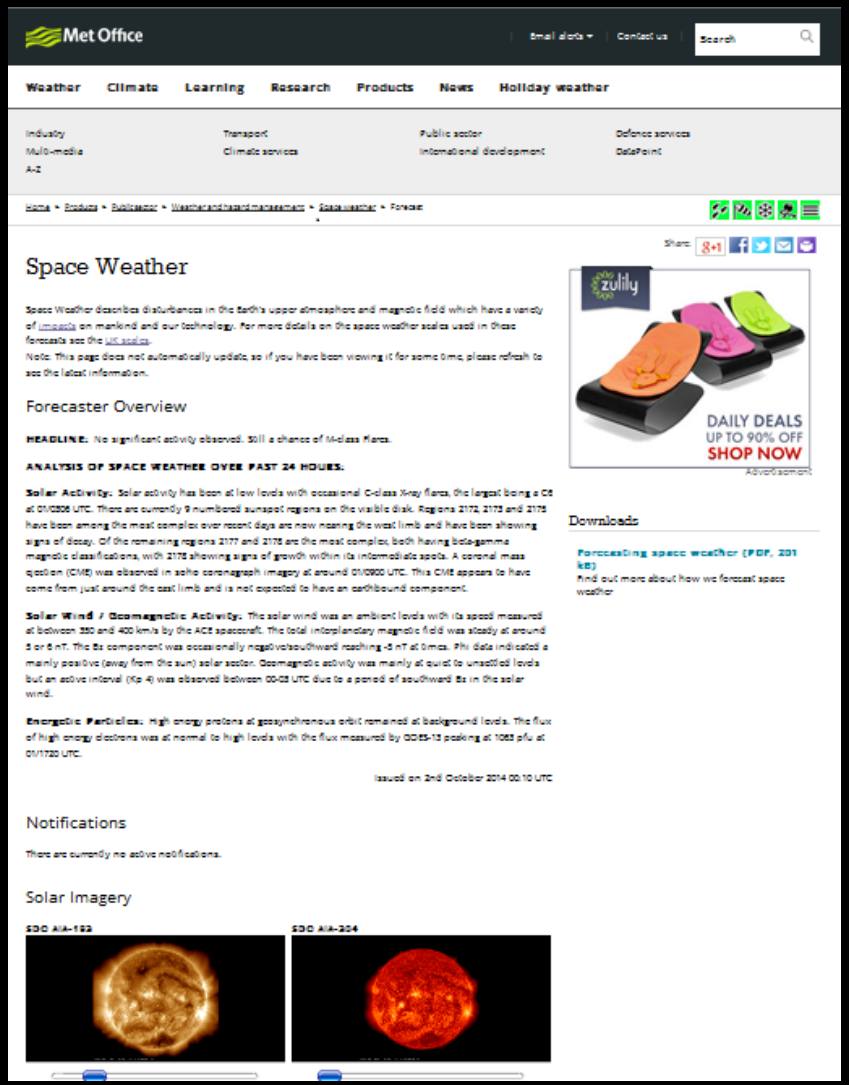
Met Office Space Weather Operations Centre (MOSWOC)

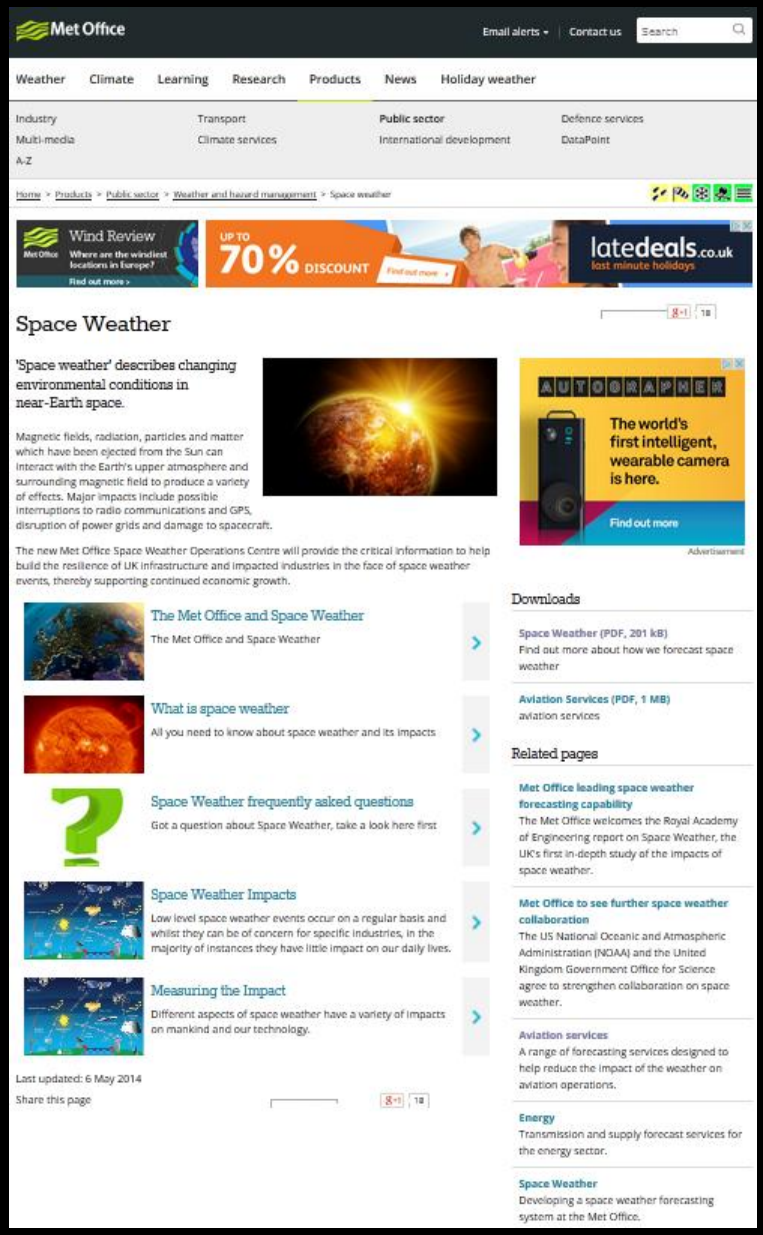
Impact scales

Category	Effect	Physical measure	Average Frequency (1 cycle = 11 years)

Category		UK Effect	US and Global Effect
Scale	Descriptor	Duration of event will influence severity of effects	
Geomagnetic Storms			
G5	Extreme	**Power systems:** Localised voltage control and protective system problems may occur leading to potential for localised loss of power. Transformers may experience damage. **Spacecraft operations:** may experience extensive surface charging, drag may increase on low-Earth-orbit satellites, problems with orientation, uplink/downlink and tracking satellites. **Other systems:** HF (high frequency) radio communication may be impossible in many areas for one to two days, GNSS(GPS) satellite navigation may be degraded for days with possible effects on infrastructure reliant on GNSS (GPS) for positioning or timing, low-frequency radio navigation can be out for hours, and aurora may be seen across the whole of the UK.	**Power systems:**widespread voltage control problems and protective system problems can occur, some grid systems may experience complete collapse or blackouts. Transformers may experience damage. **Spacecraft operations:** may experience extensive surface charging, problems with orientation, uplink/downlink and tracking satellites. **Other systems:** pipeline currents can reach hundreds of amps, HF (high frequency) radio propagation may be impossible in many areas for one to two days, satellite navigation may be degraded for days, low-frequency radio navigation can be out for hours, and aurora has been seen as low as Florida and southern Texas (typically 40° geomagnetic lat.)**.
G4	Severe	**Power systems:** No significant impact on UK power grid likely. **Spacecraft operations:** may experience surface charging and tracking problems, drag may increase on low-Earth-orbit satellites, corrections may be needed for orientation problems. **Other systems:** HF radio propagation sporadic, GNSS(GPS) satellite navigation degraded for hours, low-frequency radio navigation disrupted, and aurora may be seen across the whole of the UK.	**Power systems:** possible widespread voltage control problems and some protective systems will mistakenly trip out key assets from the grid. **Spacecraft operations:** may experience surface charging and tracking problems, corrections may be needed for orientation problems. **Other systems:** induced pipeline currents affect preventive measures, HF radio propagation sporadic, satellite navigation degraded for hours, low-frequency radio navigation disrupted, and aurora has been seen as low as Alabama and northern California (typically 45° geomagnetic lat.)**.
		Spacecraft operations: minor impact on satellite operations possible. **Other systems:** migratory animals are affected at this and higher levels; aurora is commonly visible at high latitudes (northern Michigan and Maine)**.	

Public pages





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Space Weather Energy

FORECASTER OVERVIEW

Moderate Radio Blackout observed this morning. Further M-class flare likely over the next few days. Sudden impulse at ACE at 2130 UTC possible CME from 3rd May.

Solar activity is expected to remain moderate over the coming days the large sunspot groups AR2055 and AR2056 rotate around the disc and become more geo-effective. Geomagnetic activity is expected to stay start ACTIVE but then become generally QUIET. There are a couple equatorial small coronal holes visible on the disc but their impact is thought to be minimal. With AR2051 now rotated completely out of view a proton event seems unlikely now and electrons should stay a background values.

Issued 8 May 2014 at 12:00

WARNINGS AND ALERTS

	Active alerts	Warnings
Geomagnetic	-	-
Radio blackout	-	R1 21:00 20/05 03:00 21/05
Proton flux > 100 MeV	S1 11:23-now	-
Proton flux > 10 MeV	-	-
Kp	-	-
Kuk	-	-
Electrons	-	-

GEOMAGNETIC STORM FORECAST

Probabilities of geomagnetic storms

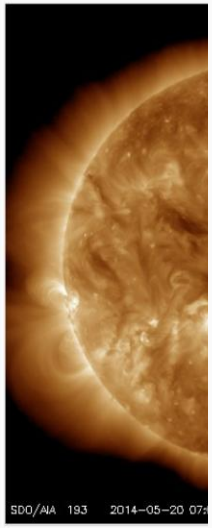
Probability	Level	Past 24 h.	Day 1	Day 2	Day 3	Day 4
Minor or moderate	G1 to G2	No	65	05	05	05
Strong	G3	No	45	01	01	01
Severe	G4	No	01	01	01	01
Extreme	G5	No	01	01	01	01
			%	%	%	%

Geomagnetic commentary

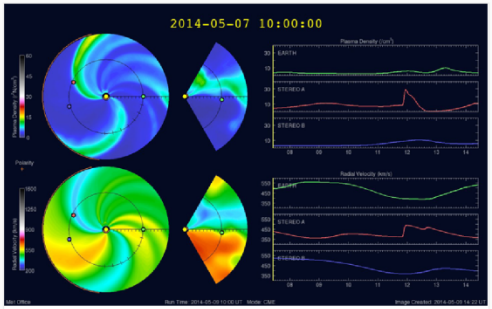
The largest flare over the last 24 hours was M1.2 flare at 16:29 UTC from AR2051 which has revolved around the western limb. With one beta-gamma spot (AR2055) and one beta-gamma-delta spot (AR2056) there is still a risk of further M-class flare activity over the next few days.

Issued 8 May 2014 at 12:00

SOLAR TIMELAPSE



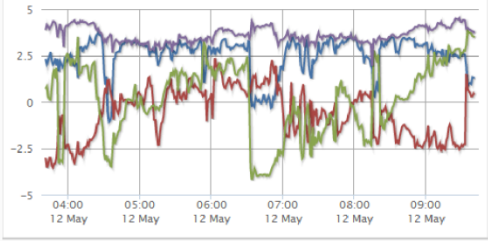
ENLIL



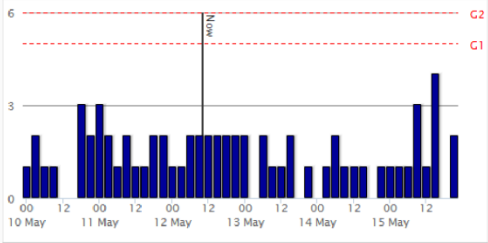
No Earth directed CMEs have been observed. Maximum solar wind speed is 500 km/s

Issued 8 May 2014 at 12:00

ACE MAGNETOMETER

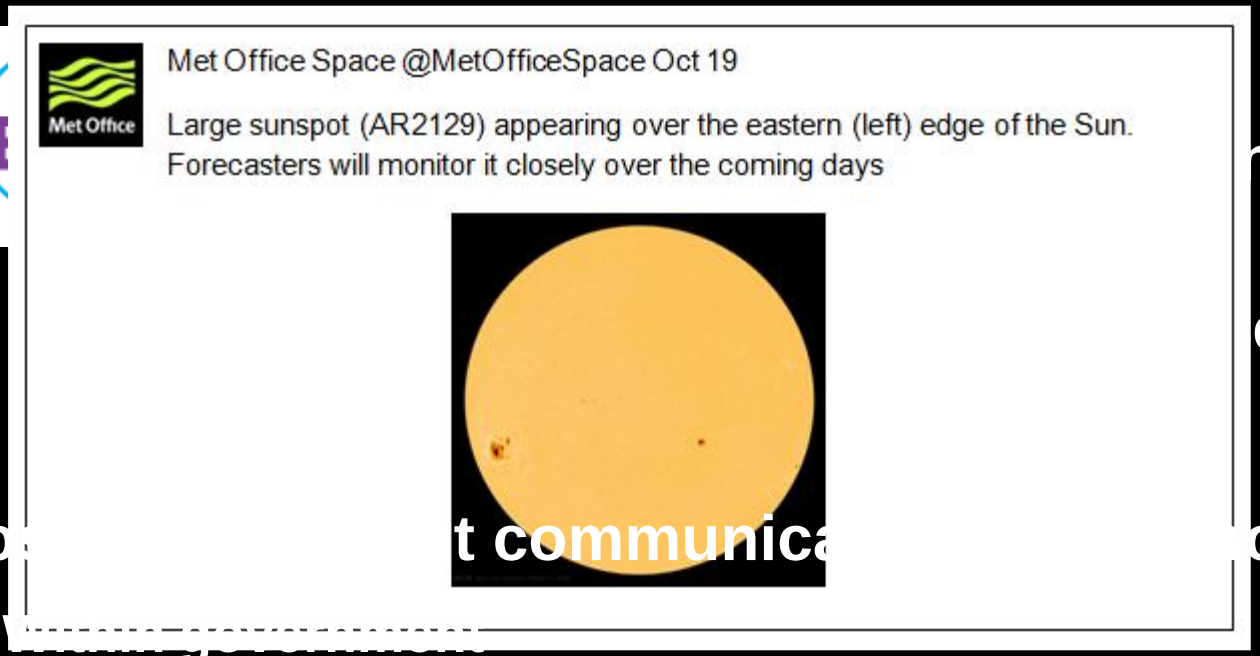


BGS 3-HOURLY KP INDEX



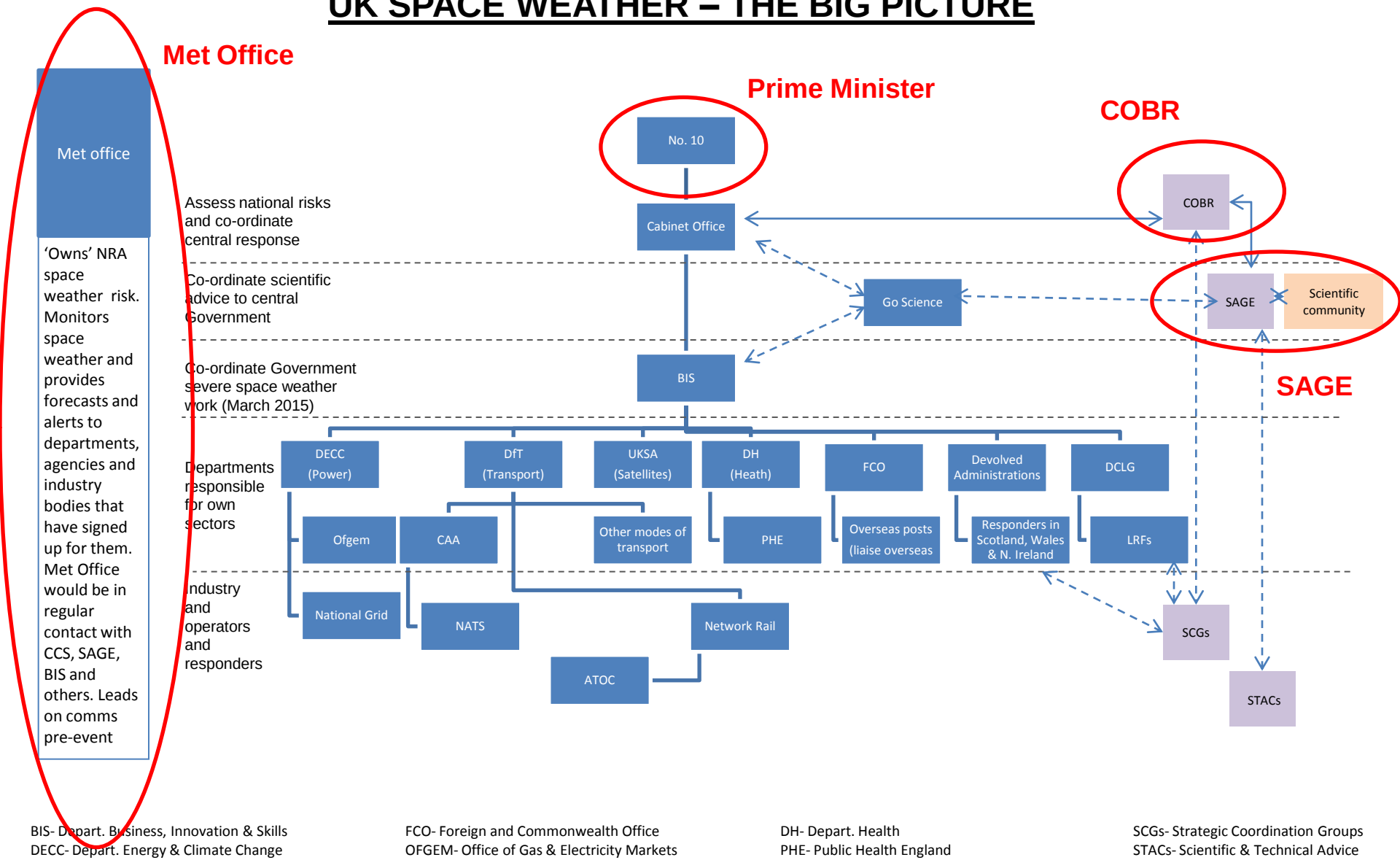
Public communication

- **Public want information**



- **Cro t communica op**
  - **Public communications**
- **UK / US bilateral meeting on public communications**

UK SPACE WEATHER – THE BIG PICTURE



BIS- Depart. Business, Innovation & Skills
DECC- Depart. Energy & Climate Change
DfT- Depart. Transport
UKSA- UK Space Agency
DAs- Devolved Administrations
DCLG- Depart. Communities and Local Government

FCO- Foreign and Commonwealth Office
OFGEM- Office of Gas & Electricity Markets
CAA- Civil Aviation Authority
ATOC- Association of Train Operating Companies
NATS- National Air Traffic Services
UKSA- UK Space Agency

DH- Depart. Health
PHE- Public Health England
LRFs- Local Resilience Forums
Posts- Overseas Diplomatic Posts
COBR- Cabinet Office Briefing Room
SAGE- Scientific Advisory Group for Emergencies

SCGs- Strategic Coordination Groups
STACs- Scientific & Technical Advice Cells
Scientific Community- British Geological Society , Science & Technology Facilities Council etc.

Products to verify

- Space weather forecasters produce guidance twice daily.
- Guidance includes probability forecasts for the next 4 days of:

1. geomagnetic storms,
2. X-ray flares,
3. high energy proton events,
4. high energy electron events.

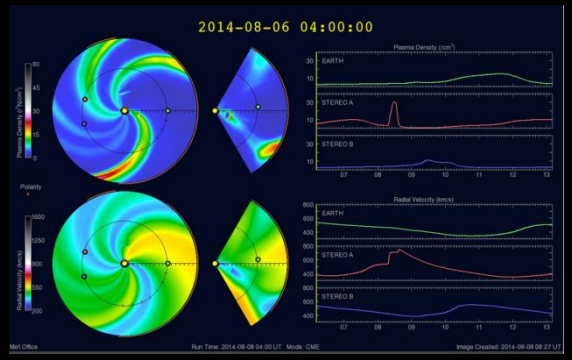
Geo-Magnetic Storm Probability (Exceedance)	Level	Past 24 Hours (Yes/No)	Day 1 (00-24 UTC) (%)	Day 2 (00-24 UTC) (%)	Day 3 (00-24 UTC) (%)	Day 4 (00-24 UTC) (%)
Minor or Moderate	G1 to G2	No	15	20	20	20
Strong	G3	No	5	5	5	5
Severe	G4	No	1	1	1	1
Extreme	G5	No	1	1	1	1

X Ray Flares Probability (Exceedance)	Level	Past 24 Hours (Yes/No)	Day 1 (00-24 UTC) (%)	Day 2 (00-24 UTC) (%)	Day 3 (00-24 UTC) (%)	Day 4 (00-24 UTC) (%)
Active	R1-R2 M Class	Yes	90	90	90	70
Very Active	R3 to R5 X Class	Yes	60	60	50	30

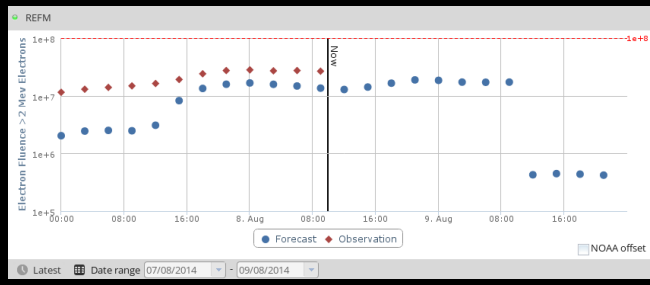
Example probability forecasts

Models to verify

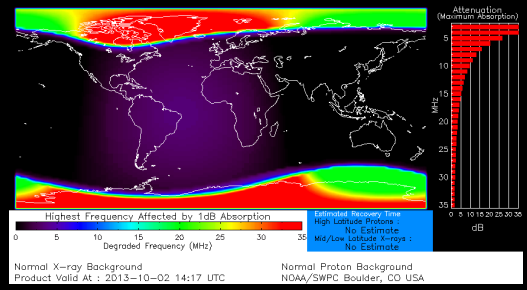
- **Enlil**: predicts solar wind speed & density between Sun & Earth for next few days.



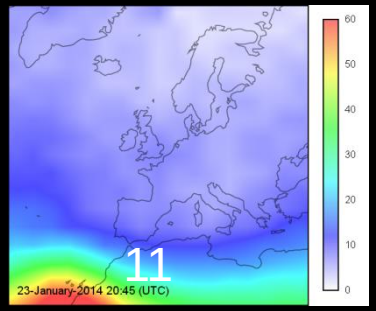
- **REFM**: 3-day forecast of high-energy electrons at GEO orbit.



- **D-RAP**: Global map of real-time D region absorption predictions.



- **MIDAS & Bernesse**: Nowcasting Total Electron Content in ionosphere.



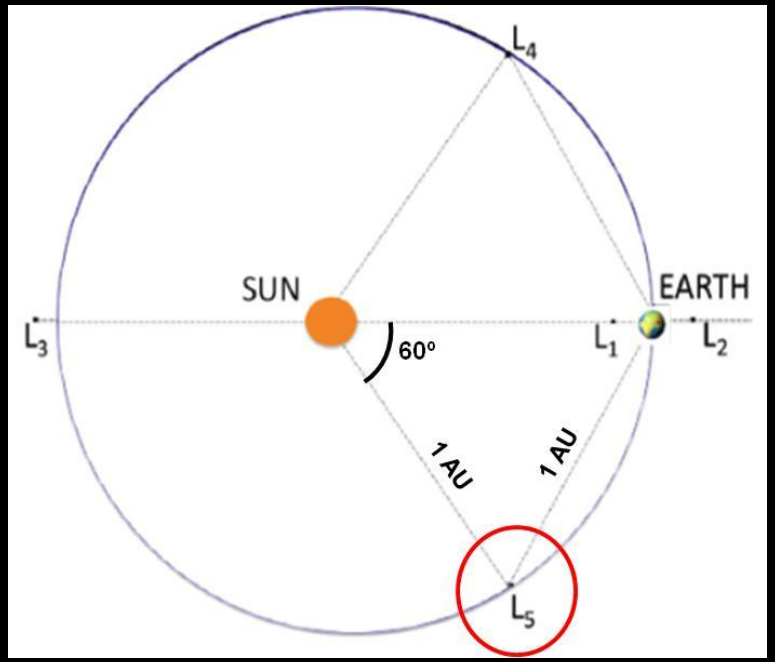
Future work

- ENLIL
  - Low resolution ensemble
  - Compare WSA with NLFF (Yeates & Mackay)
- Implement BAS Radiation-belt model
- Review magnetospheric models
  - BATSRUS / GUMICS
- SEP model (UCLan Cross-field diffusion code)
- Forecaster competency framework

Future work

- Socio-economic study – funding approved
- Working with SWPC & SANSA
  - Cost of space weather
  - Benefits of forecasts
  - Benefits of monitoring assets

- Developing off-Sun-Earth satellite proposal
- L5 workshop, London 11-14 May



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Met Office

Met Office Space Weather Technical Forecast

Space Weather Technical Forecast (Ref: MO43)

Issued on Sunday, 01 February 2015 at 17:44 local

This scientific guidance document provides a four-day assessment of space weather events. The probabilities stated below are for reaching or exceeding the given levels. For more information about space weather impacts please see the Met Office Space Weather Scales http://www.metoffice.gov.uk/media/pdf/h/a/14_0627-space-weather-4pp-nx_WEB.pdf

1200 UPDATE: No changes to the forecast. The anticipated high speed solar stream from CH30 is now underway, with a rapid increase to 540km/s at the time of writing. So far Bz has been mainly positive, often strongly, with an erratic Phi angle indicative of catching the edge of a coronal hole. The Phi appears to be mainly positive (away from the Earth at 180 degrees) during periods of enhanced solar wind. Geomagnetic activity is currently at the unsettled end of quiet (Kp2) with an increasing chance of unsettled to active periods looking likely today. Flare activity remains low with two C2 flares since midnight, one from AR2268 at 01/0432UTC and the other from AR2277 at 01/0844UTC. A filament eruption along the East limb just north of the equator occurred between 0800-0900UTC this morning, most likely resulting in a small non-Earth directed CME (CME evidence already starting to show on STEREO A chronograph imagery at 01/1016UTC). A plasma jet also came out of AR2275 at 01/0933UTC on the west limb, which may also have produced a small non-Earth directed CME.

Space Weather Forecast Headline: No Significant Activity. Chance of Minor Storm Sunday 01 and Monday 02 February.

Analysis of Space Weather Activity over past 24 hours:

Solar activity has been Low over the last 24 hours, with the largest flare of the period a C1.8 from sunspot region 2268 at 21:35 UTC. There are now six numbered sunspot regions on the earth-facing solar disc, with 2268 and 2277 still large and complex, while 2276 and 2278 have both decayed to plage.

Analysis of available Lasco imagery did not show any Coronal Mass Ejections (CMEs) released through Saturday, meaning that there are not thought to be any CMEs en route at present. Geomagnetic activity has ranged from Quiet to Active in the past day, with a peak of 4- for Kp and 4o for Kuk. Bt peaked at 12nT, with Bz ranging between -9 to +8nT. The solar wind has been relatively stable, peaking near 460km/s, while phi changed from largely negative during the morning (towards the sun) to mainly positive thereafter, finally becoming more erratic into the evening.

There were no solar radiation storms on Saturday, with recent elevated >10MeV proton levels gradually declining in the wake of the hiatus in recent M-class flare activity. Finally, >2MeV electrons at geosynchronous orbit have remained at Background flux throughout.

Four-Day Space Weather Forecast Summary:

Moderate solar activity is Likely in the next four days, with a flat 60% chance of M-class flares on all days, and a Slight Chance (10%) of X-class flares. While there are no CMEs thought to be en route at present, coronal hole 31 will give a Chance of Minor Storm on Sunday 01 and Monday 02 February, with Kp then fading towards midweek as the strength wanes. There is a slightly increasing chance of solar radiation storms in the four-day period: 20% chance on Sunday, rising to 25% by midweek. >2MeV electron flux is expected to rise in response to the anticipated coronal

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hole high speed stream, with the chance of the Active fluence threshold being surpassed rising from 1% on Sunday 01 February to 30% on Wednesday 04.

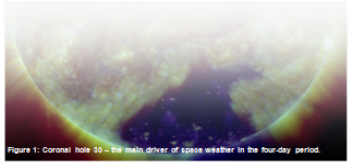

Figure 1: Coronal hole 30 – the main driver of space weather in the four-day period.

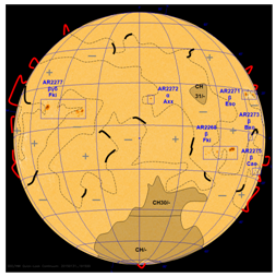

Figure 2: MOSWOC Solar Synoptic Map, valid 18 UTC Saturday 31 January.

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Geomagnetic Storms:

Analysis of available Lasco imagery shows no CMEs emitted through Saturday, meaning that there remains none en route. The dominant element of space weather in the coming four-day period is the predicted onset of the northernmost lobe of the southern polar coronal hole, labeled 'CH30+' in the MOSWOC Solar Synoptic Map. As stated in the midday update, this feature's latitude gives it a 29-day repeat period, which means the Chance of Minor Storm periods peaks on Sunday 01 February and Monday 02 (days one and two). As well as CH30+ there is a second much smaller coronal hole, CH31+ which may become geoeffective in the period. With the same polarity and similar longitude, the only distinguishing feature is likely to be a slower stream: CH30 is thought to be near 600km/s, while CH31 is a newly-emerged, less-defined and presumably weaker feature. The coronal holes' influence is expected to wane towards midweek, leading to lower probabilities of high Kp indices.

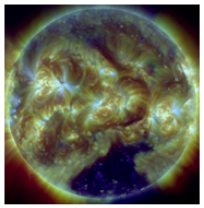

Figure 3: SDO/AIA 171/193/211 Angstrom composite image, showing the dominant dark blue of the southern polar coronal hole. The northernmost lobe is increasingly shearing forward as it reaches lower latitudes with their faster rotation than the poles.

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Met Office Space Weather Technical Forecast

Geo-Magnetic Storm Probability (Exceedance)	Level	Past 24 Hours (Yes/No)	Day 1 (00-24 UTC) (%)	Day 2 (00-24 UTC) (%)	Day 3 (00-24 UTC) (%)	Day 4 (00-24 UTC) (%)
Minor or Moderate	G1 to G2	N	30	30	10	5
Strong	G3	N	10	10	1	1
Severe	G4	N	1	1	1	1
Extreme	G5	N	1	1	1	1

Geomagnetic Activity - Earthbound Coronal Mass Ejections

Date/time 21.6R (UTC)	Halo: Full or Partial	Source	Source Location	Estimated Speed	Estimated Arrival Time	Comments
Nil						

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Radio Blackouts - X Ray Flares:

Solar activity has been Low through Saturday, with the largest flare of the day a C1.8 from sunspot region 2268 at 21:35 UTC. Activity has shown a marked downturn in the past 24 hours, with the six-hour period in M-class flares of recent days replaced by a flat GOES-15 X-ray trace near the B/C boundary today. This is despite 2277 appearing to still retain a Delta spot in its intermediate portion, with this and 2268 still Zurich Fki groups. While both groups are spreading latterly (2277 is now 23 degrees across), there is some consolidation of spots within each group, which may help to explain part of the lack of activity. MOSWOC raw global probabilities for flares remain near 80% for M-class and 20% for X based on the Fg-groups, however these are felt to be over-estimates, and have been amended downwards to 60 and 10 respectively based on sunspot age and lack of even C-class activity.

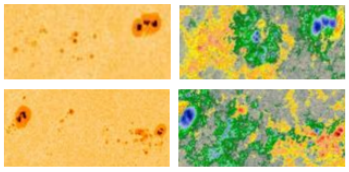


Figure 4: The two Zurich Fki groups on the disc: 2268 (top) and 2277 (bottom). HMI flattened intensitygram (left) and HMI colorized magnetogram (right). All images 22 UTC. The possible Mt Wilson Delta spot is the northeastmost-leading spot in 2277.

Met Office Space Weather Technical Forecast

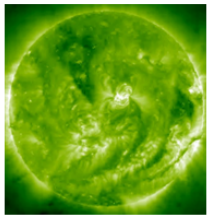


Figure 5: Stereo A EUVI 195 Angstrom image, with a notable bright region near the east limb revealing a large filament in relief. There is also a large equatorial coronal hole to the north of this, which may deliver further raised Kp indices in a week's time.

Using task-day status on the earth-facing disc, there are not thought to be any significant returning regions in the period: ex-2259 and ex-2261, which were both Mt Wilson Alpha groups. However, the southeast portion of Stereo A's EUVI 195 is the brightest portion of the far-side disc implying that there has been some development in this area in the last fortnight. The bright flux is also helping to pick out what appears to be a large filament bisecting this region and a possible coronal hole to its north – all nascent forecast elements that will need to be monitored in the next week or so.

X Ray Flares Probability (Exceedance)	Level	Past 24 Hours (Yes/No)	Day 1 (00-24 UTC) (%)	Day 2 (00-24 UTC) (%)	Day 3 (00-24 UTC) (%)	Day 4 (00-24 UTC) (%)
Active	R1-R2 M	N	60	60	60	60

Met Office Space Weather Technical Forecast

Solar Radiation Storms - (High Energy Protons):

No solar radiation storms were seen on Saturday, with >10MeV protons showing a slow decline from a peak of 1.5pfu on Friday evening. The postulated cause of the enhancement was recent flare activity, most likely a rear-sided or eastern hemisphere event owing to the slow rise and fall. The presence of two Zurich Fg-groups on the disc means that proton event probabilities are relatively high in the absence of significant flares. The westernmost group is around 40 degrees West, meaning that by day four it will be near 90 West and a prime position to effect earth should it produce a flare. Probabilities therefore rise from Slight Chance to Chance through the period.

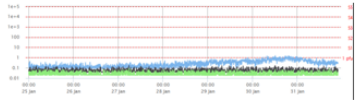


Figure 6: GOES-13 high-energy protons since 25 January. The blue line is >10MeV, showing recent enhancement.

Radiation Storms Probability (Exceedance)	Level (cm^{-2}sr^{-1}s^{-1})	Past 24 Hours (Yes/No)	Day 1 (00-24 UTC) (%)	Day 2 (00-24 UTC) (%)	Day 3 (00-24 UTC) (%)	Day 4 (00-24 UTC) (%)
Active	≥ 81	N	20	20	25	25
Very Active	≥ 69 *	N	1	1	1	1

* 83 ≥ 10 MeV ≥ 1000 pfu and / or ≥ 50 MeV ≥ 10 pfu. (pfu = cm^{-2}s^{-1}s^{-1})

Met Office Space Weather Technical Forecast

High Energy Electrons Event (≥ 2MeV)

>2MeV electrons at geosynchronous orbit have been at Background flux through Saturday, peaking at 30pfu. After having reached Moderate flux on Thursday 29 January, an Active period that evening redistributed electrons in the earth's van Allen belts, and they have since failed to recover. With the solar windspeed peaking near 450km/s on Saturday, Active fluence is a Slight Chance until the high speed stream from coronal hole 31 is well established, giving a rising risk through the period.

Radiation Storms Probability (Exceedance)	Level (cm^{-2}sr^{-1}day^{-1})	Past 24 Hours (Yes/No)	Day 1 (00-24 UTC) (%)	Day 2 (00-24 UTC) (%)	Day 3 (00-24 UTC) (%)	Day 4 (00-24 UTC) (%)
Active	≥ 2 MeV ≥ 1x10^{3}	N	1	10	20	30
Very Active	≥ 2 MeV ≥ 1x10^{4}	N	1	1	5	10

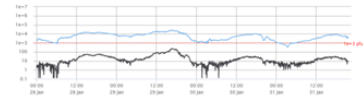
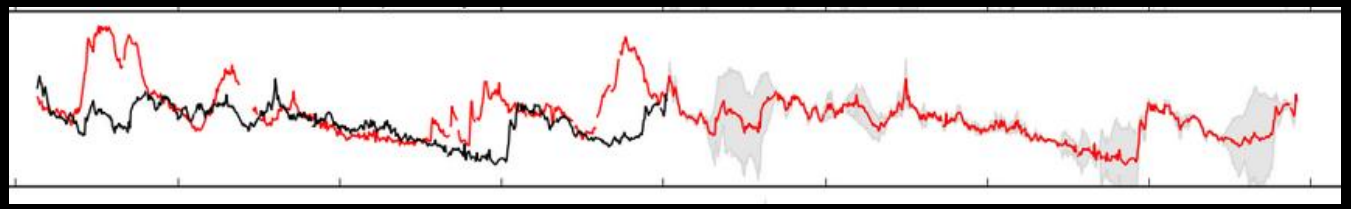


Figure 7: >2MeV high energy electrons since 28 January. Moderate flux has failed to be repeated since the raised geomagnetic activity late on 29 January.

Models



- ENLIL
- Solar wind persistence
- REFM
- DRAP
- MIDAS & Bernesse TEC maps – pre-op evaluation

Services

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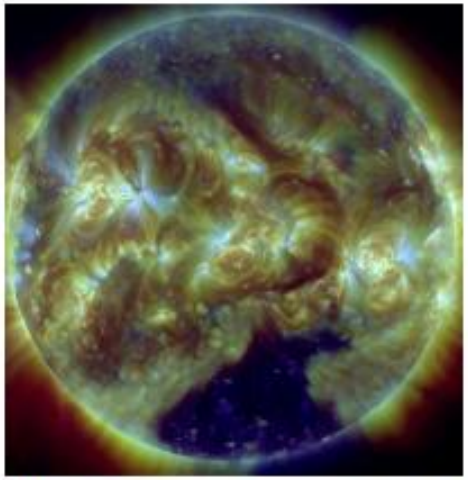

Figure 3: SDO/AIA 171/193/211 Angstrom composite image, showing the dominant dark blue of the southern polar coronal hole. The northernmost lobe is increasingly shearing forward as it reaches lower latitudes with their faster rotation than the poles.

Geo-Magnetic Storm Probability (Exceedance)	Level	Past 24 Hours (Yes/No)	Day 1 (00-24 UTC) (%)	Day 2 (00-24 UTC) (%)	Day 3 (00-24 UTC) (%)	Day 4 (00-24 UTC) (%)
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Geomagnetic Activity - Earthbound Coronal Mass Ejections

Date/time 21.5R (UTC)	Halo: Full or Partial	Source	Source Location	Estimated Speed	Estimated Arrival Time	Comments
Nil						

Met Office Space Weather Technical Forecast

Radio Blackouts - X Ray Flares:

Solar activity has been Low through Saturday, with the largest flare of the day a C1.8 from sunspot region 2268 at 21:35 UTC. Activity has shown a marked downturn in the past 24 hours, with the six-hour period in M-class flares of recent days replaced by a flat GOES-15 X-ray trace near the B/C boundary today. This is despite 2277 appearing to still retain a Delta spot in its intermediate portion, with this and 2268 still Zurich Fki groups. While both groups are spreading laterally (2277 is now 23 degrees across), there is some consolidation of spots within each group, which may help to explain part of the lack of activity. MOSWOC raw global probabilities for flares remain near 80% for M-class and 20% for X based on the F-groups, however these are felt to be over-estimates, and have been amended downwards to 60 and 10 respectively based on sunspot age and lack of even C-class activity.

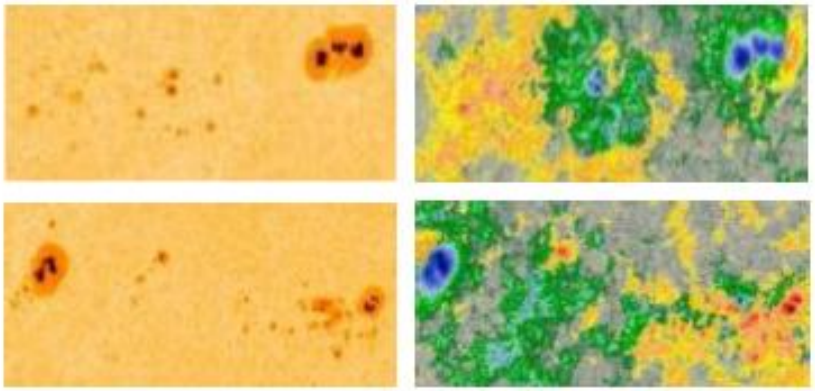

Figure 4: The two Zurich Fki groups on the disc: 2268 (top) and 2277 (bottom). HMI flattened intensitygram (left) and HMI colorized magnetogram (right). All images 22 UTC. The possible Mt Wilson Delta spot is the northeastmost-leading spot in 2277.